The Eye in the Sky - Freight Rate Effects of Tanker Supply

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Abstract

We show how the evolution of crude oil tanker freight rates depends on the employment status and geographical position of the fleet of very large crude oil carriers (VLCCs). We provide a novel measure of short-term capacity in the voyage charter market which is a proxy for the percentage of vessels available for orders. We find that our capacity measure explains parts of the freight rate evolution at weekly horizons, where traditional supply measures are uninformative. The fact that freight rates directly influence shipowners' profitability and charterers' expenditures makes our measure particularly relevant for these groups of market participants.

***Keywords*—** AIS, Crude Oil, Forward Freight Agreements, Freight Rates, Tanker Markets, VLCC.

1 Introduction

Tanker freight markets are central to the distribution of crude oil which is the largest component of global energy consumption[1]. The tanker shipping industry is a cyclical and highly volatile industry characterised erratic fluctuations in freight rates - a stylized fact which is often attributed to short-term fluctuations in the balance between supply and demand. Recently, geospatial information on vessel movements has become available from the radio signals sent by vessels' Automatic Identification Systems (AIS). AIS information enables freight market participants to track the movement of vessels within any commercial segment providing them with a detailed view of the supply side in freight markets. We study the voyage charter market

[1]According to of World Energy (2017) oil covered 33.27% of the global energy consumption in 2016. Oil is followed by coal and natural gas covering 28.11% and 24.13%, respectively, of the global energy consumption in 2016

for very large crude oil carriers (VLCC). We combine AIS information with information on vessel fixtures and propose a novel measure of available short-term capacity. Our capacity measure is negatively related to change in freight rates over a weekly horizon, where traditional supply measures are not informative. Furthermore, we show that our capacity measure adds to the freight rate price discovery above and beyond what is already explained by other market variables such as FFA rate. The fact that freight rates directly influence shipowners' profitability and charterers' expenditures make our measure particularly relevant for these market participants.

In tanker markets, the international trade of crude oil determines the demand for tanker services. The merchant fleet supplies charterers with tanker services, and the balance between demand and supply sets the level of competition. Stopford (2009) advocates a distinction between long-run supply and short-run supply of shipping services where our measure focuses on the latter. *In the long-run*, the merchant fleet evolves with the levels of investment and scrapping. *In the short-run*, the size of the merchant fleet is fixed or predetermined by the order book for new vessels. In a perfectly competitive market, freight rates are set such that they just compensate the operational costs of the marginal vessel. Demand is inelastic with respect to the freight rate, and the supply curve consists of two regimes, (Stopford 2009). For low demand levels the supply curve is very elastic as spare tonnage with similar operational costs is easily available. However, as demand increases vessels with higher operational costs, typically older vessels, enter the supply schedule. This continues to the point where no spare capacity is available. When the fleet is fully utilized, supply can only increase if vessels speed up operations. By increasing speed, vessels can increase the number of ton-miles supplied over a year. However, increasing speed also increases the operational costs as bunker consumption is convex in speed. We study the case of weekly fluctuations in supply. We argue that in the short-run some vessels may not be available to charterers. A vessel may already have found new employment, it may lack the geographical proximity to a specific loading area or its course and reported destination may suggest that it is heading for another loading region.

To the best of our knowledge, we are the first to study how AIS derived capacity measures can be used to explain the evolution of freight rates. The previous literature based on AIS information include Aßmann et al. (2015) and Adland & Jia (2016) who empirically investigate vessels' speed decisions in a Ronen (1982) model framework. In addition to being an important supply metric, vessel speeds are a key determinant of vessels' bunker consumption and thereby vessels' emission of greenhouse gases. Aßmann et al. (2015) study the speed relation for VLCC tankers, and Adland & Jia (2016) study the speed relation for Capesize carriers. Both studies find that owners do not set speed in accordance with the Ronen (1982) model. Adland & Jia (2016) suggest that the deviation from the economic theory is caused by weather conditions and contractual frictions such as charter party speed clauses[2]. Adland, Jia & Strandenes (2017) find that AIS-based volume estimates for tankers align well with custom-based export numbers. Jia et al. (2017) estimate potential fuel savings by calculation of the optimal virtual arrival point for vessels, which limits waiting time of vessels at port. Closely related to our paper, Prochazka (2018, Chapter 1) looks at contracting decisions in the VLCC tanker market. In the paper, they find a contemporaneous relationship between the freight rate level and the distance from the fixture location to the loading port. This suggests that oil buyers secure tonnage earlier during strong tanker markets, i.e., when the freight rate is high. The methodology and aim in our paper are fundamentally different from their approach as we consider different types of AIS measures. Furthermore, we aim to explain the evolution in freight rates rather than the contemporaneous relationship between AIS measure and freight rates.

Our paper has some similarities with other studies that use AIS data. For instance, Brancaccio et al. (2017) use AIS information to study search frictions and the interplay between endogenous trading costs and trade flows in dry bulk markets. They find that the matching between exporters and ships is subject to search frictions and suggest a dynamic choice ballasting model for shipowners. In a follow-up paper, Brancaccio et al. (2018) study the impact of oil prices on world trade. They show that the elasticity of world trade is asymmetric and flattens out as fuel costs decline. Their explanation for the flattening out

[2]A charter party speed clause specify the speed at which a vessel must operate during a voyage charter. See Devanney (2011).

is that shipowners' bargaining power increases as relocation of the vessel becomes cheaper. Parker (2014) sets up a matching model between VLCC tankers and cargo traders and uses AIS data as a validation tool for the speed outcomes of the matching model. Although our study shares some common features with the previous studies our focus and contribution is different as we show that the observed number of seemingly unmatched ships explains parts of the freight rate evolution.

In addition to traditional supply measures, FFA prices have also been shown to contain important information regarding the price discovery of spot (voyage) freight rates. Numerous studies have looked at FFAs ability to forecast future spot freight rates (Kavussanos & Nomikos 1999, 2003, Batchelor et al. 2007), their hedging efficiency and the volatility transmission between the FFA market and the physical freight market (Batchelor et al. 2007, Kavussanos et al. 2014, Alizadeh et al. 2015, Alexandridis et al. 2017). We find that the proposed AIS measure contains additional information about the freight rate evolution above and beyond what is already incorporated in the FFA price. The impact of supply measures on freight rate volatility is also studied in Xu et al. (2011). They analyze how the freight rate volatility depends on the size of the commercial fleet. However, studying the volatility transmission between our AIS supply measure and freight rates is beyond the scope of our paper and therefore left to future research.

In summary, the existing AIS-based papers have studied ship-operators' dynamic speed choice, the presence of search frictions in the matching process between ship-operators and charterers, or the contracting decision by charterers. The approach and findings of our paper deviates from the existing papers. We create an empirical proxy of the level of supply in tanker markets. Our classification of vessels as available or unavailable is based on the historical fixing pattern in the VLCC spot market. Based on the fixing pattern, we set up our measure of spare capacity. We show that our measure is able to explain the evolution in freight rates at short horizons where traditional supply measures are not informative. Furthermore, we show that our spare capacity measure is able to explain the evolution in spot rates above and beyond what can be explained by FFA rates. The economic magnitude of our results shows that at the average freight rate level in our sample, a standard deviation decrease in our capacity measure (decrease of 14 available vessels) leads to an increase in the freight rate level of \$0.56/mt. This corresponds to an increase in the gross freight revenue equal to \$151,200 for a typical cargo size of 270,000mt. Interestingly, we also see that the lagged change in the average speed of vessels sailing in ballast significantly predicts the evolution in the spot freight rates. This implies that vessels sailing in ballast on average decrease(increase) speed prior to an decrease(increase) in freight rates.

The outline of the rest of the paper is as follows: Section 2 describes the AIS data; section 3 shows how we construct our capacity measure; section 4 contains summary statistics, time-series plots and unit root tests; section 5 shows the estimation results; section 6 shows evidence from fixtures regressions and section 7 concludes.

2 AIS Data: Description and Properties

We have geospatial information from vessels' Automatic Identification Systems. The AIS data has kindly been provided by MarineTraffic. In addition to the AIS data, we use vessel specific information, voyage charter information, and time charter information from Clarkson's Shipping Intelligence Network (2016). We also have information on voyage charter fixtures, and time charter fixtures from Bloomberg L.P. (2016). Forward Freight Agreement data is from the Baltic Exchange.

Spot freight rates are provided by the Baltic Exchange. Each day the Baltic Exchange publishes a range of freight rate indices for a variety of routes and ship segments. We look at the TD3 tanker route, which is a VLCC route for a 265,000 mt cargo of crude oil from Ras-Tanura in the Arabian Gulf to Chiba in Japan[3]. The voyage roundtrip has a distance of 6,654nm for both the laden leg and the ballast leg. The roundtrip voyage takes approximately 50 days assuming a laden speed of 13.5 knots, a ballast speed of 12 knots, a

[3]The TD3 route is the benchmark route within our sample period. The route has recently, since 22 January 2018, been replaced by the new TD3C route which loads in the Arabian Gulf and discharges in China.

sea margin of 5% and 4 port days. The TD3 index is an index based on daily assessments regarding the prevailing spot rate provided by a panel of ship brokers. We use rates published each Friday to construct a weekly time series of the spot rates. Spot freight rates are denominated in Worldscale (WS) and have been converted to $/mt using the corresponding flat rates published by the Worldscale Association. We also include the Forward Freight Agreement price for the TD3 route. FFAs are a derivative contracts trading over the counter (OTC). The FFAs are cleared via a clearing house. The 1-month FFA contracts are settled in cash against the average of following months realized spot rates. See Alizadeh & Nomikos (2009) for a detailed description of FFAs and their usage.

Our measure relies on terrestrial and satellite-based AIS information. The International Maritime Organization's revision of the Safety for the navigation of life at sea (SOLAS) made it mandatory for vessels engaged on international voyages and weighing more than 300 gross tonnage to install an AIS transponder. This also applied to all passenger ships. We observe AIS reports at varying frequencies. Most of the time, we observe a vessel at high frequencies, such that adjacent observations are two to three minutes apart, but in a few cases observations can be days or even weeks apart. We clean the data for outliers, i.e., observations where the vessel position briefly jumps far away from the vessel's trajectory only to return to the trajectory at the next observation. We group intraday observations into daily observations for each vessel with an average speed and average draught. The draught of a vessel is the distance between the waterline and the bottom of the hull. Within our sample period from November 2014 to August 2016, we have AIS information on 676 VLCCs out of the 688 vessels present in the Clarkson's database. The AIS reports contain a time stamp as well as the vessel's latitude, longitude, course, speed in knots, self-reported draught, and self-reported destination. The self-reported fields are manually typed by a crew member. Occasionally, the self-reported fields are not up to date and at times they are even deliberately misleading. For instance we observe that crew members in certain areas report that they have armed guards on board in their destination slot. In the period where the crew signal that they have armed guards on board, they often also change their vessel's draught to reflect that they are sailing in ballast. Loaded vessels are closer to the water surface where the vessel is easier to board by pirates. This obviously introduces some noise into our measure. However, we do not believe that this affects our results.

Table 1: **AIS data summary statistics**
This table shows summary statistics for 360,350 daily vessel observations on the loading condition and vessel speeds.

	Median	Average	Std	Laden(%)	Ballast(%)	Unknown(%)
Speed	11.41	8.87	5.51			
Ballast speed	10.86	8.70	5.69			
Laden speed	11.72	9.01	5.35			
Loading condition				53.59	44.20	2.21

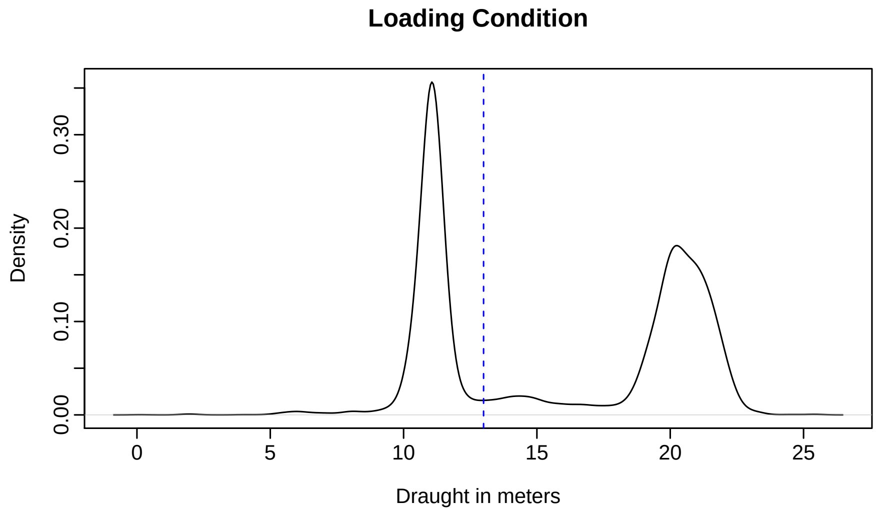
We have translated the manually typed destinations into geographical regions. Some destinations are straightforward to translate into regions as seen in the example in Table 2. Others are translated using port codes, e.g., AE FAT is translated into the Arabian Gulf as AE is the country port code for the United Arab Emirates. Sometimes, we are unable to translate the destination message into a geographical region. This is the case for messages such as ARMED GUARDS O/B, AVOID TYPHOON, DIVING OPERATION, FOR ORDERS, SEA TRIAL, etc.

Table 2: **Translation of destinations into regions example**
This table shows an example on how manually typed messages for vessels heading to Rotterdam are translated into a geographical region.

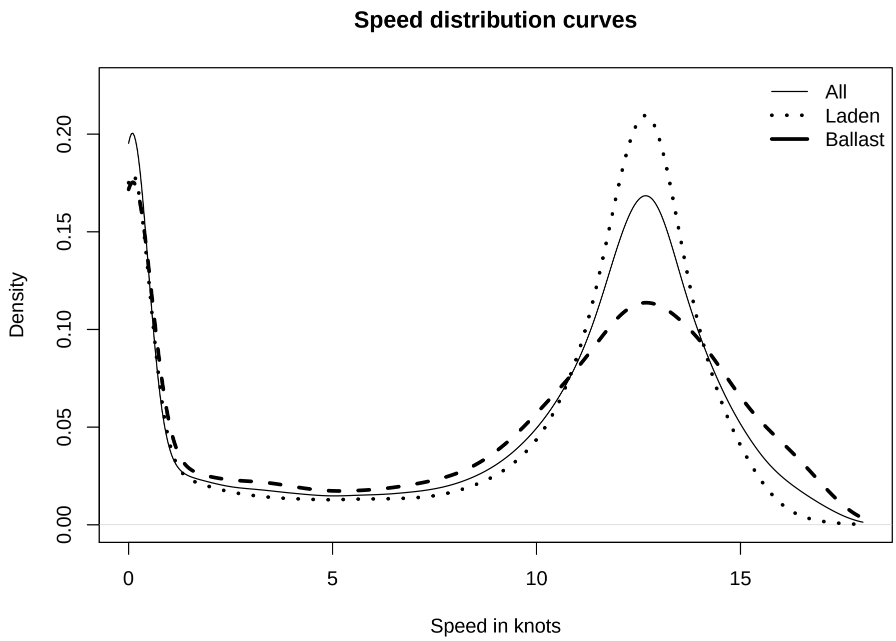
Destination	Translated region
ROTTERDAM, NL	UK AND CONTINENT
ROTTERDAM,NETHERLAND	UK AND CONTINENT
ROTTERDAM.NETHERLAND	UK AND CONTINENT
ROTTERDAM.NETHERLANM	UK AND CONTINENT
ROTTERDAME	UK AND CONTINENT
ROTTERDAN	UK AND CONTINENT
ROTTERDAR	UK AND CONTINENT

The sample period is from November 2014 to August 2016. We note that within our sample there is almost no coverage in the period between 23-27 May 2015. We determine the loading condition of the vessels from their reported draughts. Figure 1 shows the distribution of draughts and vessel speeds for daily observations. The figures show two-humped distributions. For draughts we use a cut-off point of 13 metres to distinguish between laden and vessels in ballast. For vessel speeds, we also see a bimodal distribution with a mode around zero knots and a mode around 12.70 knots.

Figure 1: **Loading condition and speed distribution**
This figure shows the distribution of reported draughts and speed density curves for daily data. The speed density curves are plotted for all vessels, laden vessels, and vessels in ballast. In panel (a), the vertical dashed line at 13 metres indicates the cut-off above which we consider vessels as laden. Panel (b) shows that the speed curves also are bimodal. There is a mode around zero knots and a mode for sailing vessels at approximately 12.70 knots.



(a) Loading condition



(b) Speed distribution curves

In our analysis, we use the average speed of the fleet. We calculate each vessel's average speed over the week and then calculate the average fleet speed as the average across all vessels.

We use information on fixtures from Clarkson and Bloomberg. Clarkson's shipping intelligence network contains 4582 VLCC voyage charters from 1 January, 2014 to 31 August, 2016 and provides information on the day of the fixture, the start and the end of the laycan period[4], the loading region, the discharge region, the agreed voyage charter rate, the charterer, the shipowner, and the cargo quantity. The Bloomberg dataset comprises voyage charter and time charter information. We use data from both sources to increase our coverage of observed trades. The use of multiple sources also introduces duplicates of trades. Often, the day a voyage charter is reported differs across different sources. The Bloomberg dataset only contains information on the beginning of the laycan period and not the end. We will use the fixtures to determine whether a vessel is available or whether she has already entered into a new charter party. For this purpose, we use the ship's IMO number, the date that the fixture is reported, and the end of the laycan period for Clarksons fixtures, and the beginning of the laycan period for Bloomberg fixtures. A set of voyage charter duplicates will mark a vessel as fixed in overlapping periods. Within the sample, 212 voyage fixtures cannot be matched to a vessel. For 178 of the voyage charter fixtures, both the vessel and the owner group is unknown whereas the owner group is known for the remaining 34 voyage charters.

Trading Locations

In order to define our measure of availability, we analyze the geographical distribution of the reported fixtures. As we focus on freight rates for the route between the Arabian Gulf and the Far East we are interested in vessels we can label available for voyage charters with a loading port in the Arabian Gulf. When labeling vessels as available we combine both AIS information and information from fixtures. We incorporate AIS information on the vessels' positions, their self-reported draughts and their self-reported destination. We combine the AIS information with the fixtures information to proxy which vessels that

[4]The laycan period is the time window within which the shipowner must tender notice of readiness to the charterer. The notice of readiness ensures the charterer that the ship has arrived at the loading port and is ready to load the cargo.

have already found new employment. We use information on the day the fixture is reported and the laycan period. When a vessel enters a fixture, it will be considered unavailable from the day the fixture is reported until five days past its laycan. On the sixth day after the laycan period, the vessel will still be considered unavailable if she is not sufficiently close to her discharge region. Our measure is set up to mimic the geographical trading locations of VLCCs which are loading in the Arabian Gulf. In this section, we show that vessels which are "fixed" (entering into new voyage charter contracts) to load a cargo of crude oil from the Arabian Gulf are typically sailing in ballast back from the Far East and the South East Asian region. However, laden vessels which approach their discharge destinations also enter new fixtures.

We start by looking at the trading locations for vessels sailing in ballast. Figure 2 shows 1064 positions for vessels reported as *"fixed"* with a loading port within the Arabian Gulf. The locations are graphed on the day the fixtures are reported. We have translated the self-reported destinations into destination regions. The trading pattern shows that vessels are entering new fixtures throughout the entire ballast leg. In 614 of the cases, vessels report the Arabian Gulf as their destination when their fixture is reported. However, east of the Strait of Malacca vessels also report either the Southern Pacific Oceania Region (SPORE)[5] or the Far East as their destination. Vessels heading for the SPORE region continue their ballast leg towards the Arabian Gulf. Three hundred and sixteen have the SPORE region as their reported destination when the fixture is reported. The Far East comes in third with 74 reports. The Far East vessel reports consist of two types. The first type consists of vessels still in port. The second group comprises vessels which have started sailing their ballast leg but have not yet updated their self-reported destination. As mentioned earlier, some of the self-reported entries are not always up to date at all points in time. Finally, vessels with unknown destination typically report that they have armed guards on-board, or that they are open for orders[6].

[5]SPORE consists of Singapore, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam.

[6]Figure 7 in appendix A shows the fixing pattern for vessels in ballast which will load in West Africa. We distinguish between vessels heading for the Arabian Gulf and West Africa by adding a condition. We categorize vessels with a southwest bound course, positioned south of the latitude of 3.9 degrees as vessel heading towards West Africa even if they report a destination within the Arabian Gulf.

Figure 2: **Locations where vessels in ballast enter fixtures with a loading port in the Arabian Gulf**

This figure shows the trading locations for 1064 voyage charters for vessels in ballast with a loading port within the **Arabian Gulf**. The distribution of the reported destinations is 614 within the Arabian Gulf, and 316 within the SPORE region. The SPORE region consists of Singapore, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. Seventy-four are heading towards the Far East which covers China, Japan, South Korea, and Taiwan. Thirty-two has an unknown destination, 14 are heading for the East Coast of India, 6 for West Africa, 3 for West Coast of India, and 5 have other destinations. The vessels with an unknown destination signal that they are open for orders or that they carry armed security guards.

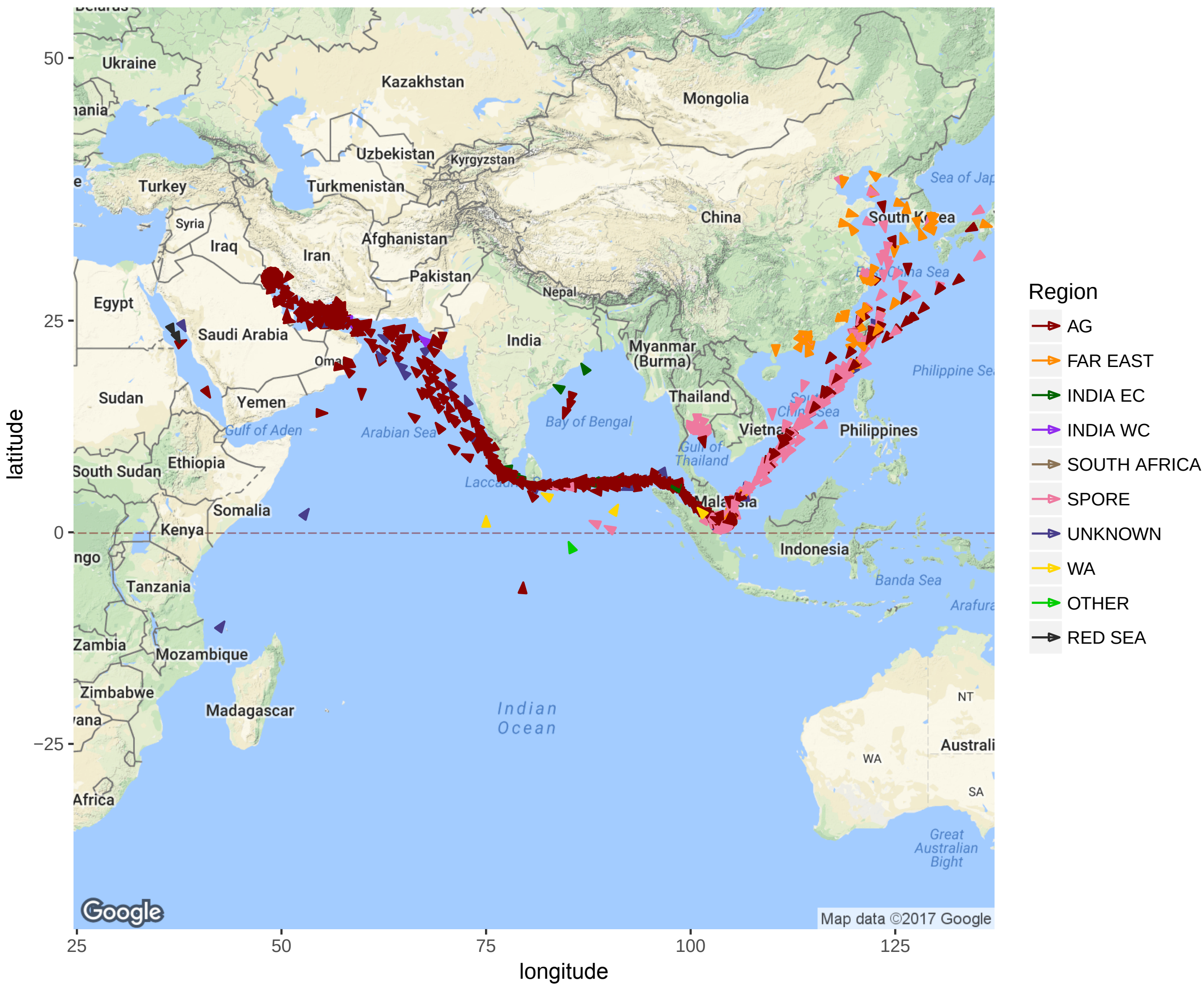
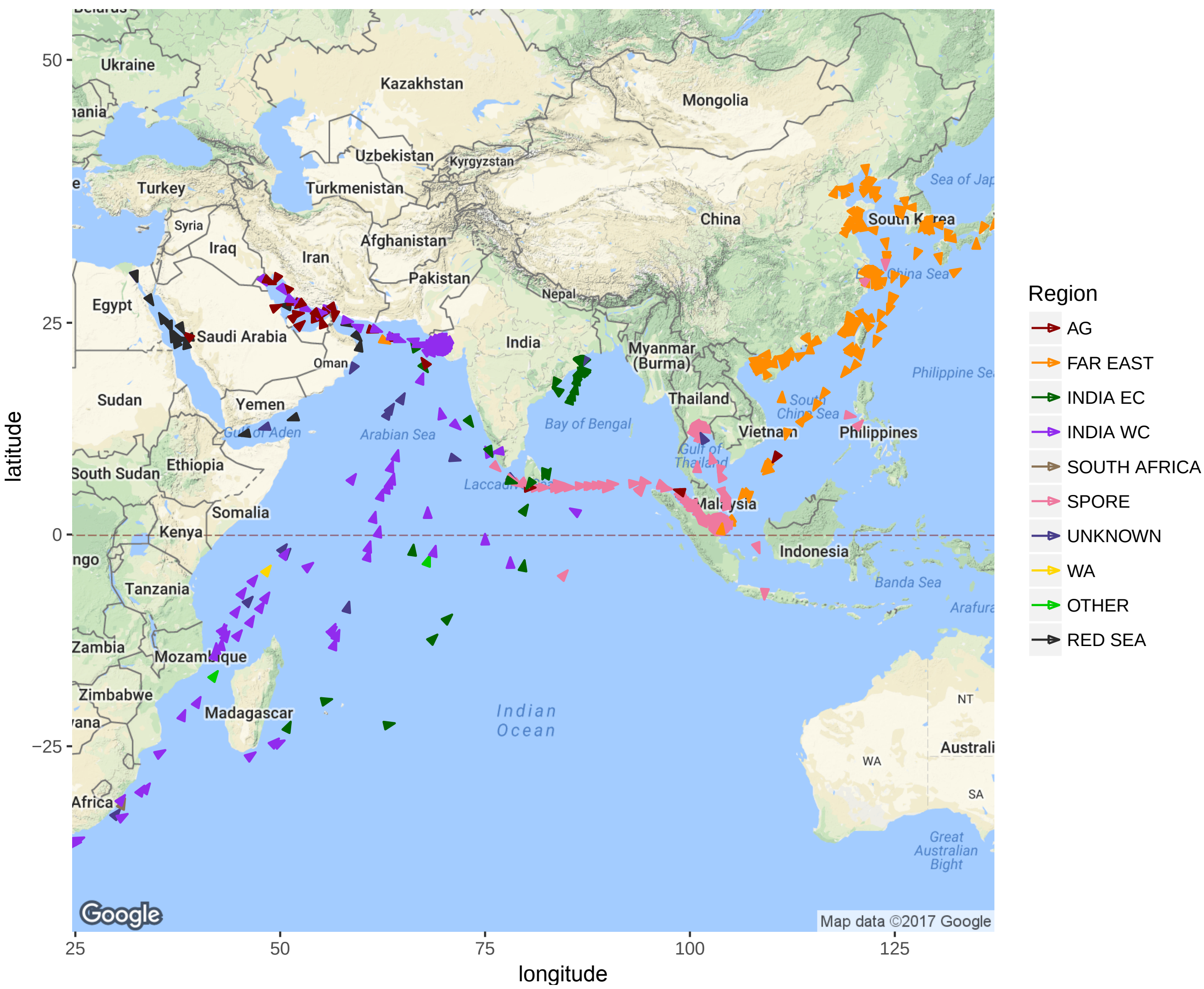


Figure 3: **Locations where laden vessels enter fixtures with a loading port in the Arabian Gulf** This figure shows the trading locations for 495 voyage charters conducted by laden vessels. The voyage charters all have a loading port in the **Arabian Gulf**. One hundred and fifty-three are heading for the Far East which covers China, Japan, South Korea, and Taiwan. One hundred and fourth-three are heading for the SPORE region, which consists of Singapore, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. Ninety-seven are heading for West India, 38 for East India, 24 sits in the Arabian Gulf, 17 has an unknown destination, and 23 have another destination. The vessels with unknown destination mainly signal that they have armed guards on-board.



We turn to the trading locations for laden vessels which *"fix"* with a loading port within the Arabian

Gulf. Figure 3 shows the location for laden vessels at the time when their fixture is reported. The figure shows how laden vessels enter into new voyage charters as they approach their destination region. We see vessels heading for West India and East India entering new trades along the East African coast. Additionally, vessels approaching Sikka, Vadinar, and Jamnagar in the Gulf of Kutch enter new trades. Vessels closing in on Visakhapatnam and Paradeep in the Gulf of Bengal enter new fixtures as well. We see similar patterns for vessels heading for the SPORE region and the Far East. They also *"fix"* as they get close to their discharge port. Vessels going towards the SPORE region start trading just west of the tip of India whereas vessels heading for the Far East trade from just east of Singapore. A few laden vessels sitting in the Arabian Gulf are also being chartered. In the smaller region segments, there are vessels heading for Egypt within the Red Sea, and the Gulf of Aden[7]. Again, vessels with an unknown destination consist of vessels using the self-reported destination slot to signal pirates that they have armed security personnel on board.

In summary, vessels in ballast enter into new voyage charters along the entire ballast leg from the Far East and South East Asia to the Arabian Gulf. We also see that laden vessels enter new voyage charters as they get close to the port of discharge. We will now set up the availability measure based on the geographical trading patterns we have described in this section.

3 Construction of the Capacity Measure

In this section, we define our availability measure. The measure reflects the number of vessels open for a voyage charter with a loading port within the Arabian Gulf divided by the number of active vessels. The measure reflects the trading patterns as well as the employment status of the fleet. The geographical component is based on AIS information and is chosen to match the trading patterns described in section 2. The ratio is the percentage of vessels *available* for spot trading divided by the of all *active* vessels in the

[7]In Figure 3 it looks as if a vessel is laden in the Suez channel, which is not possible for a VLCC. This is not the case, however, as the tip of the arrows indicates the exact location of a vessel. VLCCs do use the Suez channel. When they do, they offload part of their cargo which then gets transported by a pipeline and later reloaded onto the vessel.

VLCC fleet:

$$Ratio_t = \frac{Available\ Vessels_t}{Active\ Vessels_t}. \tag{1}$$

We expect the level of competition to increase when the ratio increases, as the number of VLCCs available for spot trading increases with the ratio. The ratio is one when all active vessels are also available for spot trading; this reflects a scenario of fierce competition among shipowners for cargoes going out of the Arabian Gulf. The opposite extreme is when the ratio approaches zero. In this case, all vessels have either already found new employment or are not satisfying the geographical restrictions. This resembles a situation where cargo owners in the Arabian Gulf face difficulties in securing ships for their cargoes and are forced to pay premium rates in the spot market.

3.1 Active vessels

At any given point in time, we consider a VLCC *active* if she has been delivered for service and is trading in the market. We discard the vessels of the National Iranian Oil Company (NIOC). Before 16 January 2016, Iran faced embargo restrictions from the European Union and the United States of America. From the AIS data, we can see that NIOC vessels carry out voyages to the Far East both before and after 16 January, 2016. However, they do not show up in our sample of publicly reported fixtures and, for this reason, we discard them from our analysis.

3.2 Available vessels

We characterize a vessel as *available* if she satisfies certain geographical restrictions and has not already entered into a new voyage contract. Starting with the geographical restriction, a vessel is available if she is either sailing in ballast towards the Arabian Gulf, or carrying cargo and about to reach her destination. To be explicit about our restrictions, a vessel is available if:

1. She is sailing in **ballast** and within a sailing distance of 6264 n.m. of the Arabian Gulf (see Figure 8 in appendix B), which is equivalent to 18 days of sailing at 14.5 knots. Furthermore, she has to

have a self-reported destination within the Arabian Gulf or the SPORE region[8]. We exclude vessels heading towards West Africa by removing vessels in ballast positioned south of the latitude of 3.9 on a southwest-bound course, i.e. courses between 90° and 270°. In addition, we also consider vessels in ballast with a self-reported destination in the Far East within 2000 n.m. of Chiba. We do this to account for the vessels in ballast that fix from a port in the Far East, and the vessels which have started their ballast leg but not yet updated their destination status.

2. She is **laden**, has a self-reported destination within West Coast India or East Coast India[9], and is within 4000 n.m. of Sikka (see Figure 9 in appendix B).

3. She is **laden**, has a self-reported destination within the Far East[10], and is within 2000 n.m. of Chiba, Japan (see Figure 10 in appendix B).

4. She is **laden**, has a self-reported destination within the SPORE region and is within 1740 n.m. of Singapore (see Figure 11 in appendix B).

3.3 Lay-up and floating storage

A vessel will also be unavailable to charterers if she is in lay-up or used for floating storage. We expect vessels in cold lay-up to switch off their transponder such that they are not included in our sample of available vessels; at the same time, a vessel in hot lay-up near Singapore will potentially be misclassified as available when she satisfies the geographical restrictions. Similarly, vessels on time charter, which are reported to be used as floating storage facilities are classified as unavailable.

[8]Some vessels use the self-reported destination field to indicate that they are available. An example is a self-reported destination being "FOR ORDERS" or simply "ORDERS". These are considered available in addition to vessels with destinations within the Arabian Gulf.

[9]Vessels sailing along the East Coast of Africa typically change their destination to signal that they have armed guards on-board. To mitigate this feature, we also consider laden vessels less than 4000 n.m. from Sikka, which signal pirates that they have armed security guards, as available.

[10]The Far East covers China, Japan, South Korea, and Taiwan

3.4 Trading status

In addition to the geographical restrictions, we also limit availability based on the trading status of the individual vessels. Vessels can be unavailable for charterers if they have already entered into a voyage charter or a time charter. A voyage charter contract yields a lump sum payment for a voyage from port A to port B, and the shipowner is responsible for paying port fees, fuel costs, and crew wages. In the case of a time charter, the charterer leases the vessel for a specific period, which can range from a couple of months to several years. The charterer pays the shipowner a daily hire and is responsible for paying port fees, and fuel costs, in contrast to the voyage charter.

It is obviously harder to determine whether a vessel on a time charter is competing for voyage charter fixtures. As an example, consider a vessel which is time-chartered by an oil company. The vessel can then be internally employed and will not be competing in the voyage charter market. However, if the oil company is unable to employ the vessel internally they have the option to let the vessel compete for fixtures in the voyage charter market. We have chosen to consider vessels which are time-chartered by oil companies as unavailable. However, we do consider vessels which are time-chartered by shipping companies or operators as available.

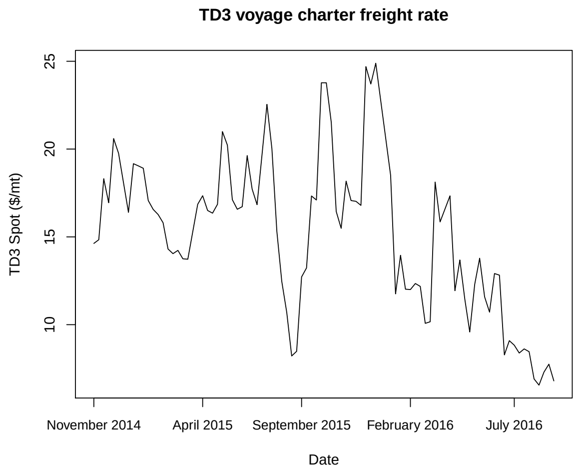
We will now turn to the availability restrictions for vessels in the voyage charter market. Naturally, once a vessel enters into voyage charter, it is expected that she will stop being available in the spot market. This is not always the case. There are cases of a vessel being reported as fixed, only for this to fall through after a few days (in which case the charter is said to have *"failed on subjects"*). We therefore observe vessels entering into multiple voyage charters within time windows that do not allow for both fixtures. We do not have data on which fixtures fail on subjects. We disregard this issue and consider a vessel ineligible for additional trading once she has secured employment. We use the reported day of the fixtures and information on the laycan period to capture the feature that vessels become unavailable once they have traded. The laycan period is the time window within which the shipowner must tender notice of readiness to the charterer. The notice of readiness announces that the ship has arrived at the loading port and is ready to load the cargo. We consider a vessel as restricted from trade from the day the fixture is reported and until 5 days after the last known laycan day. The five days are added as vessels do not always update their self-reported draught immediately after loading. Most vessels continue to carry out their fixture five days past the last laycan day. They should therefore not be considered available. This is picked up by the geographical restrictions. Five days past the last known laycan day, the vessels have changed their draught report and will then be considered laden. Whether the vessel is then considered available depends on its sailing distance to its destination region.

4 Summary Statistics

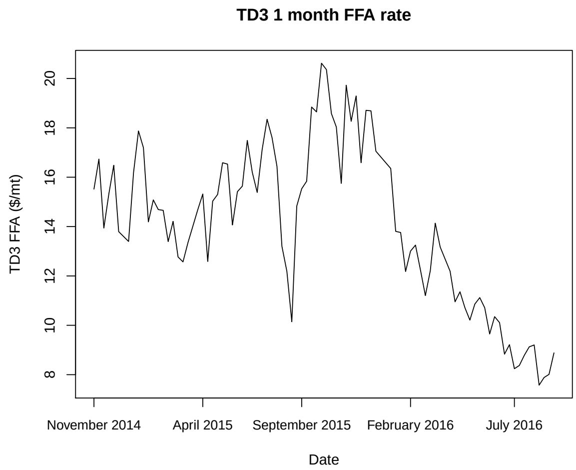
We will now provide summary statistics and unit root tests for the time-series. Figure 4 and Figure 5 show time series plots of the TD3 spot, the FFA rate, the Ratio, bunker prices in $ per metric ton, the average speed of the fleet in knots, the average speed of laden vessels in knots, the average speed of vessels in ballast measured in knots, fleet size measure in the number of vessels, and Clarkson's time-series of vessels due to arrive in the Arabian Gulf within the next four weeks.

Table 3 lists the range, median, average, and standard deviation for both the levels and log differences of the series. The voyage charter freight rate has an average over the sample period of $14.9/mt and ranges between $6.5/mt and $24.9/mt. The ratio has an average of 33.8% and ranges between 28.3% and 39.5%. The average speed for the entire fleet is 12.3 knots on average and ranges between 11.6 knots and 12.7 knots. For the differenced series, averages do not differ significantly from zero. Jarque & Bera (1980) tests reject the null hypothesis that the skewness and kurtosis of the spot rates, FFA rates, and the ratio match the skewness and kurtosis of a normal distribution. Table 4 shows Dickey & Fuller (1981), Phillips (1988), and Kwiatkowski et al. (1992) unit root tests. The results show that spot freight rates, FFA rates and bunker prices are non-stationary while their log differences are stationary. On the other hand, the capacity ratio, the average total speed, the average ballast speed and the average laden speed are stationary in levels.

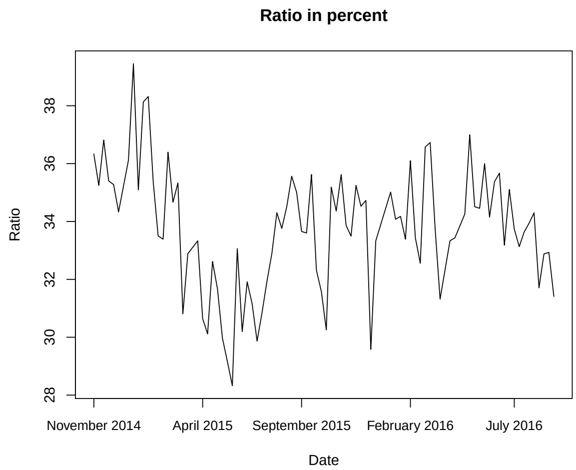
Figure 4: **Freight Rate, Availability Ratio and Bunker Price Time series plots**
This figure shows the TD3 Spot and TD3 FFA series in \$ per mt. The Ratio is the ratio of available vessels to active vessels. The bunker fuel price is 380 cst Fujairah bunker price in \$ per mt. The sample period runs from 14 November, 2014 to 26 August, 2016, and the sampling frequency is weekly.



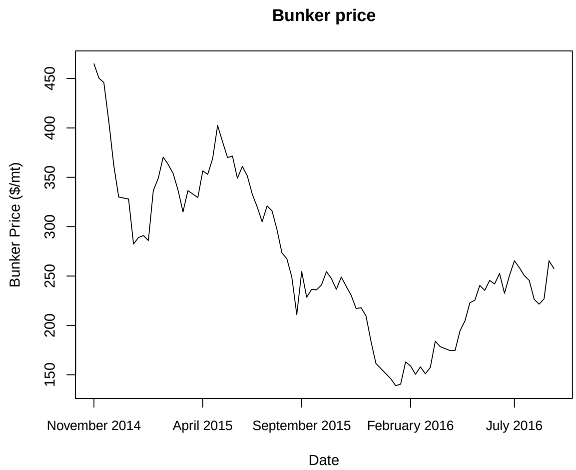
(a) TD3 Voyage Charter Rate



(b) TD3 FFA Rate

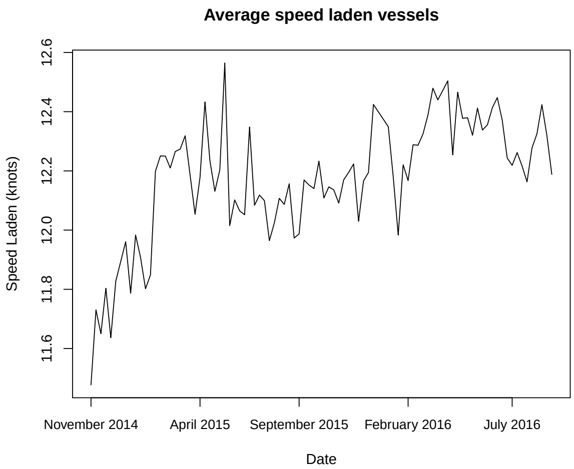


(c) Availability Ratio

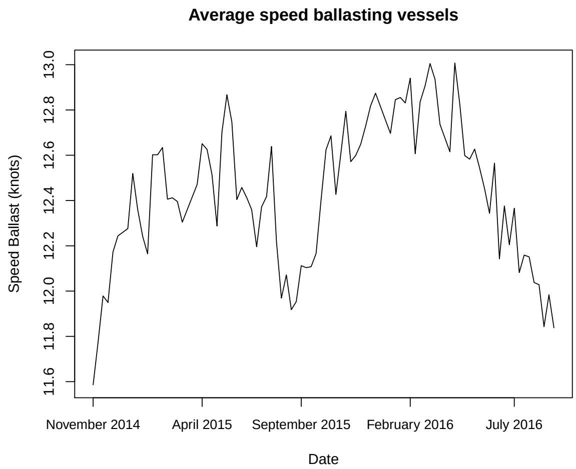


(d) Bunker price

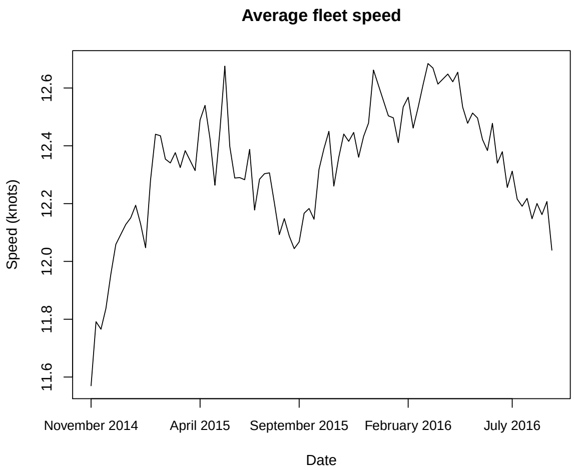
Figure 5: **Average Speed Time series plots**
This figure shows the average speed in knots for the entire fleet, the laden vessels and the vessels sailing in ballast.



(a) Speed Laden Vessels

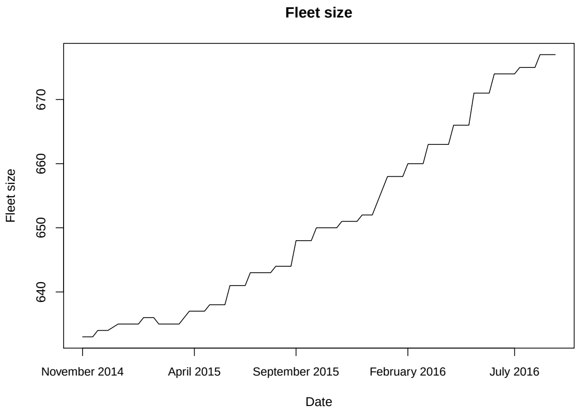


(b) Ballast Speed

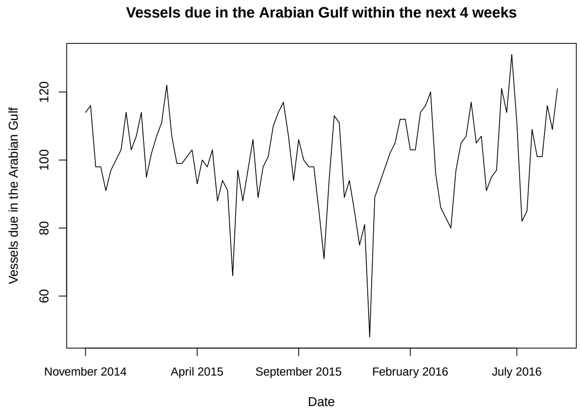


(c) Fleet Speed

Figure 6: **Time series plots 3**
This figure shows the fleet size and Clarkson's measure of vessels due in the Arabian Gulf within the next four weeks.



(a) VLCC fleet size



(b) Vessels due in the Arabian Gulf

Table 3: **Summary Statistics**

This table shows summary statistics. The sample period runs from 14 November 2014 to 26 August 26, 2016 and time-series have a weekly frequency. Both the TD3 Spot and TD3 FFA series are in $ per mt. The Ratio is the ratio between available vessels and active vessels. Speed is the weekly average of the fleet's speed in knots for vessels sailing above 6 knots. Similarly, the ballast speed and laden speed are the average speeds for the vessels sailing in ballast and laden respectively. Fuel is the 380 cst Fujairah bunker price in $ per mt. Fleet size is the number of VLCCs in the fleet and vessels due are the expected number of vessels which will reach the Arabian Gulf within the next four weeks. The sample period is from the 14 November, 2014 to the 26 August, 2016, and the sampling frequency is weekly.

Panel A: Levels

	Average	Std	Median	Min	Max
TD3 Spot	14.9	4.5	15.6	6.5	24.9
TD3 FFA	14.1	3.5	14.7	7.5	20.6
Ratio	33.8	2.2	33.8	28.3	39.5
Speed	12.3	0.2	12.3	11.6	12.7
Speed Ballast	12.2	0.2	12.2	11.5	12.6
Speed Laden	12.4	0.3	12.4	11.6	13
Bunker Fuel Price	268.3	78	251.5	139	465
Fleet Size	651.1	14.4	650	633	677
Vessels Due	100.2	13.5	101	48	131

Panel B: ln Differences

	Average	Std	Median	Min	Max	Skewness	Kurtosis	J-B Statistic	J-B p-value
TD3 Spot	0.003	0.05	0.002	-0.1	0.3	1.9	10.3	473.2	0
TD3 FFA	0.002	0.04	0.001	-0.2	0.2	0.5	6.8	184.0	0
Ratio	-0.002	0.1	-0.002	-0.2	0.2	0.1	0.2	0.6	0.7
Speed	0	0.01	0.001	-0.02	0.02	-0.04	-0.04	0.03	1.0
Speed Ballast	0	0.01	0	-0.03	0.04	-0.1	-0.2	0.2	0.9
Speed Laden	0.001	0.01	0.001	-0.04	0.03	-0.3	1.7	13.6	0.001
Bunker Fuel Price	-0.01	0.1	-0.02	-0.2	0.2	0.4	0.3	3.5	0.2
Fleet Size	0.001	0.002	0	-0.002	0.01	2.7	7.5	344.6	0
Vessels Due	0.001	0.2	0.02	-0.5	0.6	0.4	2.7	33.5	0

Table 4: **Unit root tests**

This table shows test statistics for unit root tests. ADF is the Augmented Dickey & Fuller (1981) test. The lag order is chosen by minimizing the SBIC criteria, Schwarz (1978). The ADF regression includes an intercept. PP is the Phillips (1988) test. The critical values for the ADF and PP test are -3.51 at a 1% level, and -2.89 for a 5% level. KPSS is the Kwiatkowski et al. (1992) unit root test. The null hypothesis in the Kwiatkowski et al. (1992) test states that the time series is stationary. The critical values are 0.463 at a 5% level, and 0.739 at a 1% level. We use log differences for the unit root tests of the differenced time series. Asterisks denote significant tests such that ** indicates significance at a 1% confidence level, and * indicates significance at a 5% level.

	ADF L	ADF D	PP L	PP D	KPSS L	KPSS D
TD3 Spot	-2.494	-7.925**	-2.580	-10.127**	0.914**	0.097
TD3 FFA	-1.435	-7.473**	-1.238	-9.213**	1.093**	0.164
Ratio	-3.618**	-9.381**	-5.460**	-15.168**	0.224	0.053
Speed	-2.834	-8.402**	-3.537**	-11.024**	0.688*	0.597*
Speed Laden	-3.368*	-9.184**	-4.339*	-14.153**	1.400**	0.216
Speed Ballast	-2.392	-8.240**	-2.960*	-12.440**	0.350	0.431
Bunker Fuel Price	-2.490	-5.969**	-2.603	-9.285**	1.655**	0.270
Fleet Size	0.850	-8.956**	1.158	-11.360**	2.411**	0.408
Vessels Due	-4.380**	-9.641**	-5.506**	-14.166**	0.192	0.048

5 Results

5.1 Comparison with traditional supply measures

In this section, we compare our AIS capacity measure with the traditional supply measures. The traditional measures are fleet size and the speed of the vessels in the merchant fleet, Beenstock & Vergottis (1989). The empirical analysis of shipping market supply measures are mainly conducted with annual and monthly frequencies. Before AIS data was available, the speed of vessels were unobservable to the econometricians which therefore relied on proxies to capture the dynamics of the speed of the fleet. In a Ronen (1982) model framework, the natural logarithm of the optimal speed is linearly related to the natural logarithm of the ratio between freight rates and bunker prices. In addition to fleet size and the freight rate bunker ratio, we also look at the number of VLCCs due in the Arabian Gulf within the next 4 weeks reported by Clarkson's shipping intelligence network.

Table 5 shows predictive regressions for the weekly evolution in freight rates for the traditional supply measures and the AIS-based supply measures. We find that the traditional measures of supply - such as fleet size, freight to bunker ratio, vessels due to AG, are statistically insignificant and thus cannot explain the weekly-evolution in freight rates. We find a significant effect from our ratio of available vessels to active vessels and from the fleet speed of vessels sailing in ballast. A potential explanation for the significant effect from the speed of vessels sailing in ballast is that shipowners slow down when they expect lower freight rates going forward. Another possible explanation is that shipowners are compensated for ballasting faster to reach their laycan through a higher freight rate. In column (10) we test the joint significance of the ratio and the ballasting speed. The F-test for the joint removal is rejected even though the p-value for both variables are statistically insignificant, the p-values being 6.61% and 5.98% for the ratio and ballast speed, respectively.

Table 5: **Predictive regressions on supply measures**

This table shows predictive regressions of the weekly evolution in freight rates on the supply measures: the number of available vessels over the number of active vessels, fleet size, the freight rate bunker price ratio, the fleet speed of vessels sailing in ballast, the fleet speed of vessels sailing laden, the number of VLCCs due to arrive in the Arabian Gulf within the next four weeks. Standard errors are in parentheses.

	Dependent variable: ln *differences in the TD3 freight rate*									
	$\Delta TD3_t$									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
$\Delta \ln Ratio_{t-1}$	-0.567^{*}									-0.522
	(0.284)									(0.281)
$\Delta \ln Fleetsize_{t-1}$		6.892								
		(9.243)								
$\ln Fleetsize_{t-1}$			-0.001							
			(0.003)							
$\Delta \ln(TD3/Bunker)_{t-1}$				-0.029						
				(0.102)						
$\ln(TD3/Bunker)_{t-1}$					0.001					
					(0.006)					
$\Delta \ln \underset{Ballast}{Speed_{t-1}}$						2.484^{*}				2.296
						(1.216)				(1.205)
$\Delta \ln \underset{Laden}{Speed_{t-1}}$							-1.678			
							(1.492)			
$\Delta \ln(Vessels\ Due)_{t-1}$								-0.152		
								(0.111)		
$\ln(Vessels\ Due)_{t-1}$									-0.002	
									(0.004)	
Observations	93	93	93	93	93	93	93	93	93	93
R^2	0.042	0.006	0.002	0.001	0.0005	0.043	0.014	0.020	0.002	0.078
Adjusted R^2	0.031	-0.005	-0.008	-0.010	-0.010	0.033	0.003	0.009	-0.00	0.058
F Statistic	3.994^{*}	0.556	0.226	0.084	0.044	4.170^{*}	1.265	1.890	0.224	3.870^{*}
Note:	$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$									

5.2 The FFA spot rate vector error correction model

In this section, we nest our measure into the VECM framework to see whether the freight rate price discovery of our measure is already captured by the FFA price. This also allows us to study the lead-lag relationship between our availability measure and the spot freight rate. Granger (1981), Engle & Granger (1987), Johansen (1988), and Johansen (1995) introduced the VECM framework. We start by considering the Vector Auto Regressive (VAR) model representation. We set up the VECM from the Vector Autoregressive VAR model with p lags. We assume that all individual variables are either $I(1)$ (integrated of order one), or $I(0)$ (integrated of order zero) such that stationarity can be achieved in all of the k variables by taking first differences. The VAR(p) model is defined by:

$$y_t = \sum_{i=1}^{p} \boldsymbol{A}_i y_{t-i} + u_t. \tag{2}$$

where y_t is a $k \times 1$ vector containing the levels of the time series, $\boldsymbol{A}_i$ are $k \times k$ matrices of coefficients for $i \in \{1, \cdots, p\}$, and $\boldsymbol{u}_t$ is an error term of dimension $k \times 1$. $\boldsymbol{u}_t$ is a white noise process and has a contemporaneous covariance matrix $\boldsymbol{\Sigma}$ of dimension $k \times k$. By subtracting y_{t-1} on both sides, we take the first difference, and since all variables are either $I(1)$ or $I(0)$, this will achieve stationarity. We then arrive at the vector error correction form:

$$\Delta y_t = \alpha\beta' y_{t-1} + \sum_{i=1}^{p-1} \boldsymbol{\Gamma}_i \Delta y_{t-i} + u_t. \tag{3}$$

where Δ denotes the first difference operator such that $\Delta y_t = y_t - y_{t-1}$. $\alpha\beta' y_{t-1}$ is the error correction term which is related to the VAR(p) model in equation (2) by $\alpha\beta' = -(\boldsymbol{I}_k - \boldsymbol{A}_1 - \cdots - \boldsymbol{A}_p)$[11]. Furthermore, $\boldsymbol{\Gamma}_i = -(\boldsymbol{A}_{i+1} + \cdots + \boldsymbol{A}_p)$ for $i = \{1, ..., p-1\}$. Both α and β are $k \times r$ matrices where r is the number of cointegration relationships. $\beta' y_{t-1}$ gives a stationary linear combination of variables in levels. The FFA spot basis has been used in many studies of vector error correction models of spot freight rates and FFA prices. It is therefore natural to nest our new availability measure into a model of this class. See Kavussanos

[11] $\boldsymbol{I}_k$ is the identity matrix of dimension k.

& Nomikos (1999), Kavussanos & Nomikos (2003), Kavussanos et al. (2004), Batchelor et al. (2007), and Alexandridis et al. (2017) for VEC freight rate models.

We will now estimate the vector error correction model with the spot freight rate and the FFA price as dependent variables, and the lagged ratio as the independent variable. This is the simplest extension of the Kavussanos & Nomikos (1999), Kavussanos & Nomikos (2003), Kavussanos et al. (2004), and Batchelor et al. (2007) type VECM specification, which contains our capacity measure, in addition to the spot freight rate and the FFA price. The vector containing the dependent variables is:

$$y_t = [\ln TD3_t \ \ \ln FFA_t]$$

We estimate a VECM with one lag as suggested by the SBIC criterion (Schwarz 1978) (see Table 10 in appendix C). We then test whether the cointegration rank for $\ln TD3_t$ and $\ln FFA_t$ is zero or one. Both the Johansen (1991) eigenvalue test (in Table 11 in appendix C) and the trace test (in Table 12 in appendix C) suggest that the cointegration rank is one. Furthermore, the over-identification restriction test (in Table 13 in appendix C) shows that the cointegration relationship can be restricted to be the difference between the logarithm of the voyage charter freight rate and the logarithm of the one-month FFA price, i.e. the log-basis, $\ln TD3_t - \ln FFA_t$. We then estimate the coefficients α and $\mathbf{\Gamma}_1$ from equation (3), which are shown in Table 6. We note that the voyage charter rate tends to decrease(increase) after an increase(decrease) in the availability ratio. In addition, the evolution of the voyage charter rate is negatively related to the spot - FFA basis which means that spot freight rates tends to increase(decrease) when the FFA rate is above(below) the voyage charter rate.

In order to quantify the economic impact, we consider a one standard deviation decrease in our capacity measure. In Table 3, we see that the sample average of our capacity measure is 33.8%, corresponding to 211 vessels satisfying the availability restrictions and 624 active vessels on average during our sample period. A one standard deviation decrease in our capacity measure, i.e. 2.2 percentage points between period $t-1$

and period t, implies an increase in freight rates of approximately[12] 3.75% . At the average freight rate level, this corresponds to an increase in the freight rate of \$0.56/mt, which leads to an increase in gross freight revenue equal to \$151,200 for a typical cargo-size of 270,000mt. Finally, we note that the evolution in the FFA rates cannot be explained by the past values of the ratio, voyage charter rates, FFA prices, nor the difference between the voyage charter rate and the FFA price.

Our sample period is November 2014 and August 2016. Our sample overlaps with the global Oil Glut during which oil prices dropped significantly. Expenses for bunker fuel is as mentioned the main component of voyage costs. A natural concern is that oil price movements are driving the evolution in freight rates. We control for oil prices in two ways. First, we add bunker prices to the predictive regression. Second, we look at predictive regressions for the time charter equivalent freight rate earnings which are not affected by fluctuations in bunker prices. In table 7, we see that when we control for bunker prices the availability ratio becomes significant at a five percent level rather than only at the ten percent level. Furthermore, results in table 8 shows that results are statistically even stronger when we look at the time charter equivalent earnings rather than voyage rates.

[12]At average values, this corresponds to a decrease in available vessels from 211 to 197. All other things being equal, a one standard deviation decrease in our capacity measure will, at sample average values for the ratio and the freight rate, increase freight rates by 3.75%$= -0.558 \cdot \ln\left(\frac{\bar{Ratio} - sd(Ratio)}{\bar{Ratio}}\right)$

Table 6: **VECM estimation**
This table shows the coefficients of the vector error correction model from equation (3) where $p = 2$ and the error correction term is $ECT_t = \beta' y_t = [\ln TD3_t - \ln FFA_t]$.
Variance inflation factors $\text{VIF}_i = \dfrac{1}{1 - R_i^2}$ are
$\text{VIF}(ECT_{t-1}) = 1.21$
$\text{VIF}(\Delta \ln Ratio_{t-1}) = 1.01$
$\text{VIF}(\Delta \ln TD3_{t-1}) = 1.61$
$\text{VIF}(\Delta \ln FFA_{t-1}) = 1.60$

	Dependent variable:	
	$\Delta \ln TD3_t$	$\Delta \ln FFA_t$
	(1)	(2)
$\Delta \ln Ratio_{t-1}$	-0.558^{*}	0.028
	(0.271)	(0.192)
$\Delta \ln TD3_{t-1}$	0.029	0.069
	(0.122)	(0.086)
$\Delta \ln FFA_{t-1}$	0.061	-0.231
	(0.187)	(0.133)
$\ln TD3_{t-1} - \ln FFA_{t-1}$	-0.343^{***}	-0.086
	(0.096)	(0.068)
Observations	92	92
R^2	0.191	0.040
Adjusted R^2	0.155	-0.003
F Statistic (df = 4; 88)	5.205^{***}	0.925
Note:	*p<0.05; **p<0.01; ***p<0.001	

Table 7: **Predictive regressions**

This table shows predictive regressions where the error correction term is $ECT_t = \beta' y_t = [\ln TD3_t - \ln FFA_t]$. Standard errors are in parentheses. $\text{VIF}_i = \dfrac{1}{1 - R_i^2}$ in column (6) are

$\text{VIF}(ECT_{t-1}) = 1.24$
$\text{VIF}(\Delta \ln Ratio_{t-1}) = 1.03$
$\text{VIF}(\Delta \ln TD3_{t-1}) = 1.84$
$\text{VIF}(\Delta \ln FFA_{t-1}) = 1.67$
$\text{VIF}(\Delta \ln Bunker_{t-1}) = 1.14$
$\text{VIF}\left(\underset{Ballast}{\Delta \ln Speed_{t-1}}\right) = 1.07$
$\text{VIF}\left(\underset{Laden}{\Delta \ln Speed_{t-1}}\right) = 1.04$

	Dependent variable:					
	$\Delta \ln TD3_t$					
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln Ratio_{t-1}$		-0.544^{*}		-0.493	-0.523	-0.539^{*}
		(0.263)		(0.257)	(0.268)	(0.267)
$\underset{Ballast}{\Delta \ln Speed_{t-1}}$			2.784^{*}	2.603^{*}	2.452^{*}	2.472^{*}
			(1.119)	(1.107)	(1.157)	(1.155)
$\underset{Laden}{\Delta \ln Speed_{t-1}}$					-1.118	-1.163
					(1.395)	(1.393)
$\Delta \ln TD3_{t-1}$					0.008	0.058
					(0.121)	(0.128)
$\Delta \ln FFA_{t-1}$					0.035	-0.006
					(0.184)	(0.187)
$\Delta \ln Bunker_{t-1}$						-0.287
						(0.246)
$\ln TD3_{t-1} - \ln FFA_{t-1}$	-0.350^{***}	-0.346^{***}	-0.363^{***}	-0.359^{***}	-0.348^{***}	-0.358^{***}
	(0.087)	(0.086)	(0.085)	(0.084)	(0.094)	(0.094)
Observations	93	93	93	93	92	92
R^2	0.149	0.187	0.203	0.234	0.241	0.253
Adjusted R^2	0.140	0.169	0.186	0.209	0.188	0.191
F Statistic	16.100^{***}	10.483^{***}	11.602^{***}	9.182^{***}	4.545^{***}	4.107^{***}
Note:	*p<0.05; **p<0.01; ***p<0.001					

Table 8: **Predictive regressions for the time charter equivalent earnings**
This table shows predictive regressions for the evolution in time charter equivalent earnings. The error correction term is $ECT_t = \beta' y_t = [\ln TD3TCE_t - \ln FFATCE_t]$. Standard errors are in parentheses. $\text{VIF}_i = \dfrac{1}{1-R_i^2}$ in column (6) are
$\text{VIF}(ECT_{t-1}) = 1.12$
$\text{VIF}(\Delta \ln Ratio_{t-1}) = 1.03$
$\text{VIF}(\Delta \ln TD3TCE_{t-1}) = 1.77$
$\text{VIF}(\Delta \ln FFATCE_{t-1}) = 1.48$
$\text{VIF}(\Delta \ln Bunker_{t-1}) = 1.14$
$\text{VIF}\left(\Delta \ln \underset{Ballast}{Speed_{t-1}}\right) = 1.06$
$\text{VIF}\left(\Delta \ln \underset{Laden}{Speed_{t-1}}\right) = 1.04$

	Dependent variable:					
	$\Delta \ln TD3TCE_t$					
	(1)	(2)	(3)	(4)	(5)	(6)
$\Delta \ln Ratio_{t-1}$		-0.743^{*}		-0.673^{*}	-0.731^{*}	-0.763^{*}
		(0.338)		(0.329)	(0.339)	(0.335)
$\Delta \ln \underset{Ballast}{Speed_{t-1}}$			3.838^{**}	3.596^{*}	3.224^{*}	3.254^{*}
			(1.434)	(1.415)	(1.466)	(1.450)
$\Delta \ln \underset{Laden}{Speed_{t-1}}$					-1.380	-1.472
					(1.766)	(1.747)
$\Delta \ln TD3TCE_{t-1}$					-0.004	0.089
					(0.150)	(0.157)
$\Delta \ln FFATCE_{t-1}$					0.239	0.170
					(0.220)	(0.221)
$\Delta \ln Bunker_{t-1}$						-0.534
						(0.309)
$\ln TD3TCE_{t-1} - \ln FFATCE_{t-1}$	-0.500^{***}	-0.502^{***}	-0.517^{***}	-0.517^{***}	-0.507^{***}	-0.526^{***}
	(0.105)	(0.103)	(0.102)	(0.100)	(0.107)	(0.106)
Observations	93	93	93	93	92	92
R^2	0.198	0.239	0.257	0.290	0.306	0.330
Adjusted R^2	0.190	0.222	0.241	0.266	0.258	0.275
F Statistic	22.783^{***}	14.290^{***}	15.736^{***}	12.253^{***}	6.332^{***}	5.980^{***}
Note:	*p<0.05; **p<0.01; ***p<0.001					

6 Evidence from fixtures

In this section we look at the evidence from individual voyage charter fixtures, to ensure our results are not purely driven by vessel specific characteristics. We estimate a freight rate panel-regression for the individual fixtures as in Alizadeh & Talley (2011) and Adland et al. (2016). This way we control for vessel- and fixture-specific characteristics. We estimate regression coefficients in a fixtures regression where we regress the natural logarithm of the freight rate on the natural logarithm of the ratio. We also control for the utilization rate of the vessel given as the cargo size in mt divided by the vessel's dead weight tons, a dummy equal to one if the vessel is more than 15 years old, the DWT(in 100,000) of the vessel, the log-distance from the vessel to the loading region, the natural logarithm of the bunker price at the time where the fixture is reported, the natural logarithm of of the FFA price at the time when the fixture is reported, and the fleet size measured by the number of vessels.

The expected signs of the regression coefficients are the following: We expect our capacity measure to be negatively related to the freight rate level as rates should be higher when there are fewer vessels available for orders. The utilization rate is expected to be negatively related to the freight rate, the reason being that the differences in voyage costs for a fully loaded and partially loaded vessel are not substantially different. A partially loaded vessel will still need to pay port charges and sail to the discharge port. Hence, a partially loaded cargo should result in a high freight rate in $ per ton given the lower amount of tons. Freight rates are expected to be decreasing with age as charterers' vetting requirements favor younger vessels; for that we include a dummy for whether the vessel's age is above 15 years. The freight rate is expected to decrease in vessel size given the increasing returns to scale in size. Freight rates are expected to increase with the vessel's distance to the loading region. The intuition here is that when freight rates are high there are few vessels close to the loading region and the charterers need to book vessels far away to make sure that they find a vessel for their cargo, (Prochazka 2018, Chapter 1). Bunker prices are expected to be positively related to the freight rate as bunker fuel constitutes the main voyage costs. When voyage costs are high, shipowners pass through costs to charterers by demanding a higher freight rate. Finally, the FFA price is expected to be positive and close to 1 given the well established long-run cointegration relationship between spot rates and FFA rates. The fleet size is expected to have a negative sign as increased number of vessels all other things equal should yield lower rates through increased competition. We do not include the TD3 index as an independent variable, given the recent critique by Adland, Cariou & Wolff (2017). We estimate the regression coefficients of the specification:

$$\ln FR_{i,t} = \beta_0 + \beta_1 \ln Ratio_t + \beta_2 Utilization_{i,t} + \beta_3 1_{\{Age_{i,t}>15\}} + \beta_4 DWT_{i,t} + \beta_5 \ln Dist\ to\ AG_{i,t} \\ + \beta_6 \ln Bunker_t + \beta_7 \ln FFA_t + \beta_8 \ln fleet\ size_t + \epsilon_{i,t}. \quad (4)$$

The panel regression results, in Table 9 column (1), show that our capacity measure is negatively correlated with the freight rate even after adjusting for vessel-specific effects in the form of vessel age, size and macro variables bunker prices, and FFA prices. Furthermore, we see that the statistical significance of our capacity measure remains when we estimate regressions with owner or charterer fixed effects which are meant to capture the influence from shipowners and charterers described in Adland et al. (2016). The result also remains when we control for vessel specific characteristics estimating a regression with vessel fixed effects. The fixed effect specifications estimate time-invariant effects for charterers, owners and vessels respectively. As an example the vessel fixed effect specification in Table 9 column (4) estimates a time-invariant intercept for each vessel instead of the common intercept β_0 specified in regression equation 4. Most of the signs of the coefficients align well with our expectations. We see that the utilization rate point estimates are negative. Vessels, which are older than 15 years, have a negative point estimate, but it is insignificant. The size measured by the vessel's DWT also has negative point estimates in all of the specifications. Distance to the loading region has a positive point estimate which we expected based on the results in Prochazka (2018, Chapter 1). Finally, as expected, bunker prices are positively related to freight rates since higher bunker prices increase voyage costs, for which shipowners need to be compensated by a higher freight rate paid by charterers.

Table 9: **Fixtures regression**

This table shows regressions where the dependent variable is the natural logarithm of the freight rate. The independent variables are the availability ratio, the fixture specific utilization ratio (the cargo size divided by the vessel size in dwt), an age dummy which equals one if the vessel's age is above 15 years, the size of the vessel in dwt, the distance to the Arabian Gulf, the bunker price, the FFA price and the fleet size. In column (2), (3) and (4), we estimate regressions with owner, charterer and vessel fixed effects to control for owner, charterer and vessels specific effects. Standard errors are in parenthesis.

	Dependent variable:			
	$\ln Freight\ Rate_{i,t}$			
	(1)	(2)	(3)	(4)
$\ln Ratio_t$	-0.47^{***}	-0.44^{***}	-0.48^{***}	-0.40^{*}
	(0.11)	(0.12)	(0.11)	(0.16)
$Utilization_{i,t}$	-2.18^{**}	-2.42^{**}	-0.85	-1.44
	(0.70)	(0.76)	(0.93)	(1.05)
$1_{\{Age_{i,t}>15\}}$	-0.03	-0.03	-0.02	0.03
	(0.02)	(0.03)	(0.02)	(0.04)
$DWT_{i,t}$	-0.60^{**}	-0.72^{**}	-0.24	
	(0.21)	(0.24)	(0.28)	
$\ln Distance\ to\ AG_{i,t}$	0.02^{**}	0.02^{***}	0.02^{**}	0.02^{*}
	(0.01)	(0.01)	(0.01)	(0.01)
$\ln Bunker\ Price_t$	0.10^{**}	0.12^{***}	0.07^{*}	0.14^{**}
	(0.03)	(0.04)	(0.04)	(0.05)
$\ln FFA_t$	0.99^{***}	0.98^{***}	0.98^{***}	1.02^{***}
	(0.04)	(0.05)	(0.05)	(0.07)
$\ln Fleet\ size_t$	-1.19	-1.25	-1.47^{*}	-1.38
	(0.66)	(0.70)	(0.68)	(1.04)
Intercept	10.30^{*}			
	(4.57)			
Owner FE	No	Yes	No	No
Charterer FE	No	No	Yes	No
Vessel FE	No	No	No	Yes
Observations	473	473	473	473
R^2	0.81	0.80	0.80	0.80
Adjusted R^2	0.80	0.76	0.78	0.53
F Statistic	242.06^{***}	197.74^{***}	211.40^{***}	115.22^{***}
Note:	$^{*}p<0.05$; $^{**}p<0.01$; $^{***}p<0.001$			

7 Conclusion

Recently, the vessel movements in the freight market has become observable via the radio signals sent by vessels' Automatic Identification System. AIS information enables freight market participants to track the movement of vessels within any commercial segment. This paper is the first to use an AIS derived capacity measure to explain the evolution in voyage charter freight rates. Our measure incorporates the geographical trading patterns observed in the VLCC market. We find that AIS supply measures are able to explain the short-term freight rate evolution where traditional supply measures such as fleet size are uninformative. Our sample period falls within the recent Oil Glut where the oil price experienced a severe drop. We find that our results get statistically stronger when we control for bunker prices or model the evolution in the time charter equivalent earnings.

Our findings suggest that AIS measures can explain parts of the freight rate evolution, which is not already explained by traditional supply measures or FFA rates. We find that the evolution of freight rates depends on the fleet's geographical distribution as well as its employment status. We find that there is a considerable economic magnitude of our measure. We see that a standard deviation decrease in our capacity measure (decrease of 14 available vessels) leads to an increase in the freight rate level of \$0.56/mt. This corresponds to an increase in the gross freight revenue equal to \$151,200 for a typical cargo size of 270,000mt. Furthermore, we also find that the speed of vessels sailing in ballast explains part of the freight rate evolution. When vessels in ballast start sailing faster(slower) this is a sign that freight rates will increase(decrease) in the following week.

Our results have implication for practitioners and academics alike. First, the proposed measure of tonnage availability is a potentially useful indicator of shipping economic activity and, as such, may be used more widely by academics and practitioners as a freight rate forecast indicator and a proxy for trading and physical market activity. Furthermore, the use of fixtures information also provides insights on the spatial chartering pattern of market participants. We encourage future research on the interplay between freight rates and AIS based measures in longer sample periods and other commercial shipping segments.

Acknowledgements

We are extremely grateful to MarineTraffic for the data sample provision. We would like to thank the reviewers as well participants at the IAME 2017 conference in Kyoto for helpful comments and suggestions. Finally, we want to thank the R Core Team (2015) free software community. Particularly, the paper has benefited from packages developed by Pfaff (2008*a*), Pfaff (2008*b*), Kahle & Wickham (2013), and Hlavac (2015). Regli acknowledges financial support from the Danish Maritime Fund.

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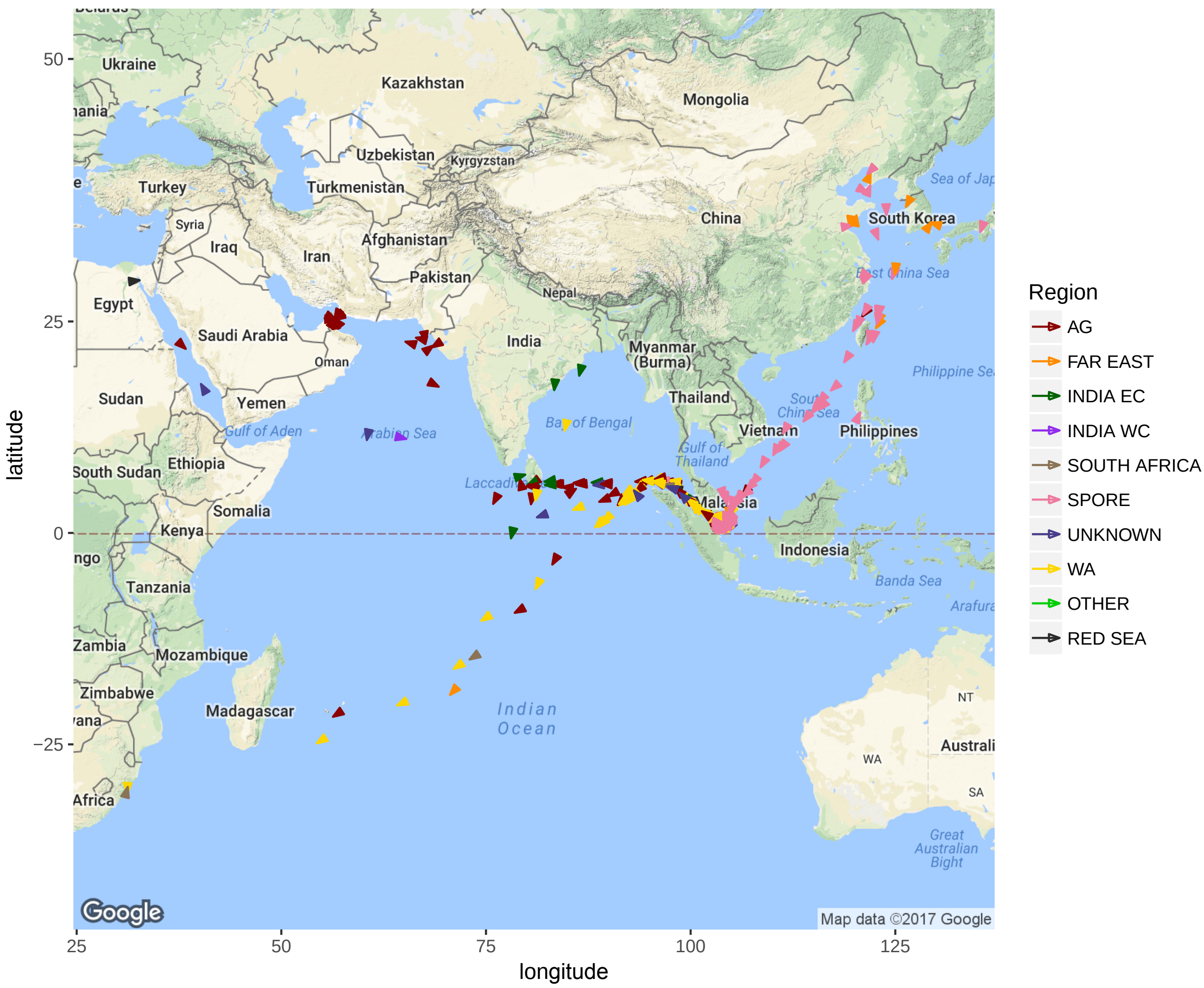
A Appendix: Fixing location for vessels sailing in ballast with a loading port in West Africa

Figure 7 shows vessels in ballast entering into fixtures *loading in West Africa*. East of Singapore, vessels are either heading for the SPORE region, the Far East or West Africa. This is similar to the pattern for vessels loading in the Persian Gulf in Figure 2. West of Singapore some of the vessels are on the direct ballast leg for West Africa, whereas others are following the ballast leg towards the Arabian Gulf. This gives the impression that some ship operators maintain the option of entering trades that load in West Africa when sailing towards the Arabian Gulf. They seem to keep this option to redirect until they pass the tip of India. The small group of vessels in the Gulf of Kutch and near Ras Tanura have not been sailed in ballast back from the Far East, but have delivered Oil in the Gulf of Kutch. At first, it seems a bit strange that these vessels fix in West Africa when the ballast leg to the Arabian Gulf is much shorter. An inspection of the sailing patterns for these vessels shows that these vessels have just completed voyages to West India and are picking up bunker fuel at Fujairah before sailing in ballast back to West Africa. Within the Indian Ocean, there are three vessels having a self-reported destination in South Africa which in our figure falls within the category: Other.

Figure 7: **Locations where vessels in ballast enter fixtures with a loading port in West Africa** This figure shows the trading locations for 255 voyage charters of vessels which are on their ballast leg. The voyage charter has a loading port in **West Africa**. 96 of the vessels report a destination within the SPORE region which consists of Singapore, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. 64 are heading for West Africa, 50 are heading for the Arabian Gulf, 12 towards the Far East which covers China, Japan, South Korea, and Taiwan. 10 are unknown and 23 report other destinations.



B Appendix: Boundary conditions

This section contains plots of the boundary conditions.

Figure 8: **Arabian Gulf proximity boundary for vessels in ballast**
This figure shows vessel positions with a sailing distance to Fujairah (the big black dot) between 6124 n.m. and 6264 n.m. which is illustrated by the small black dots. The small black dots gives an indication of the boundary of availability condition 1. The triangles are positions of vessels which enter a fixture loading in the Arabian Gulf. The colors of the triangles indicate whether the self-reported destination region is SPORE or the Arabian Gulf.

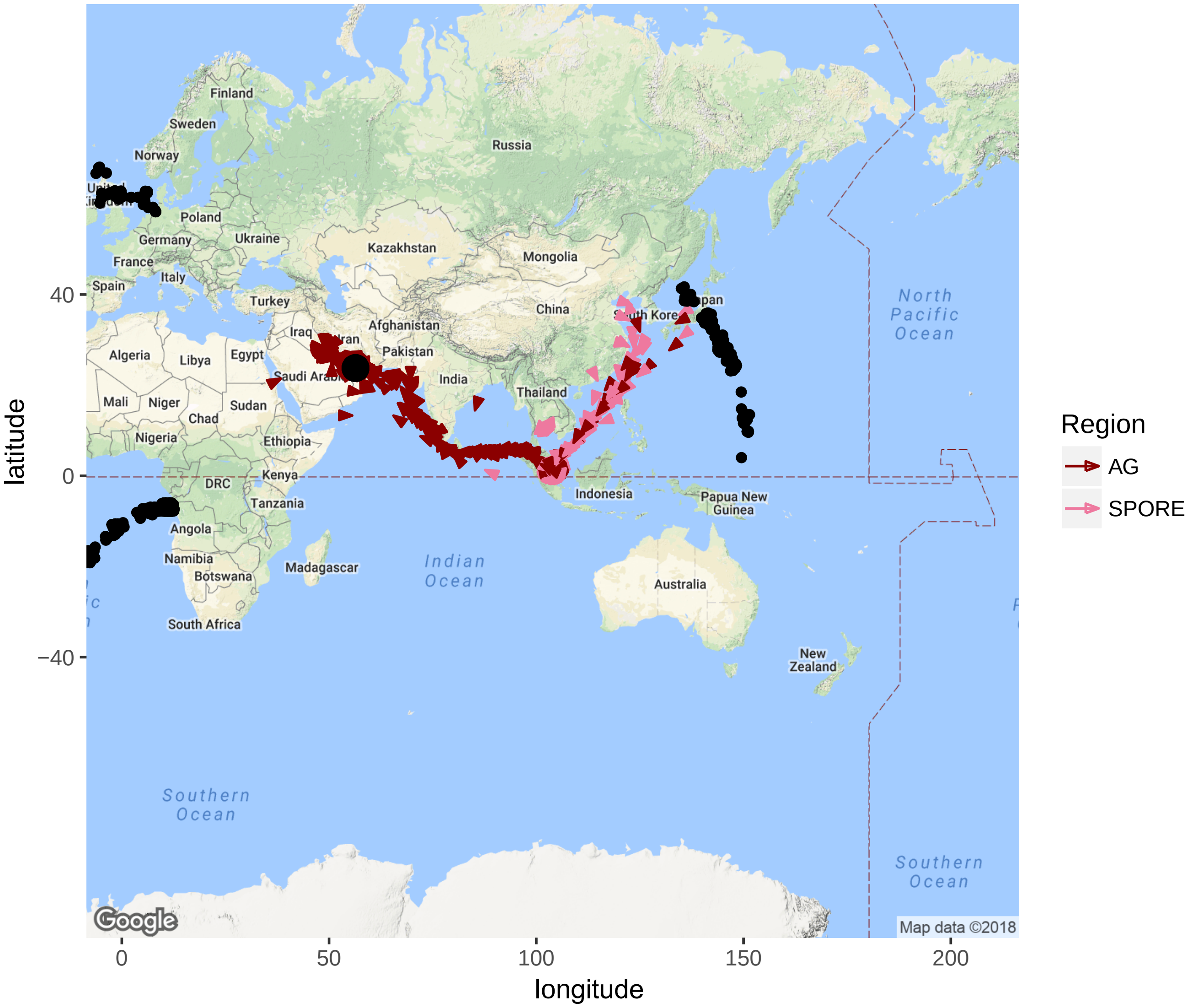


Figure 9: **India proximity boundary for laden vessels**
This figure shows vessel positions with a distance to Sikka (the big black dot) between 3900 n.m. and 4000 n.m. which is illustrated by the small black dots. The small black dots gives an indication of the boundary of availability condition 2. The triangles are positions of vessels which enter a fixture loading in the Arabian Gulf. The colors of the triangles indicate whether the self-reported destination region is the east coast of India or the west coast of India.

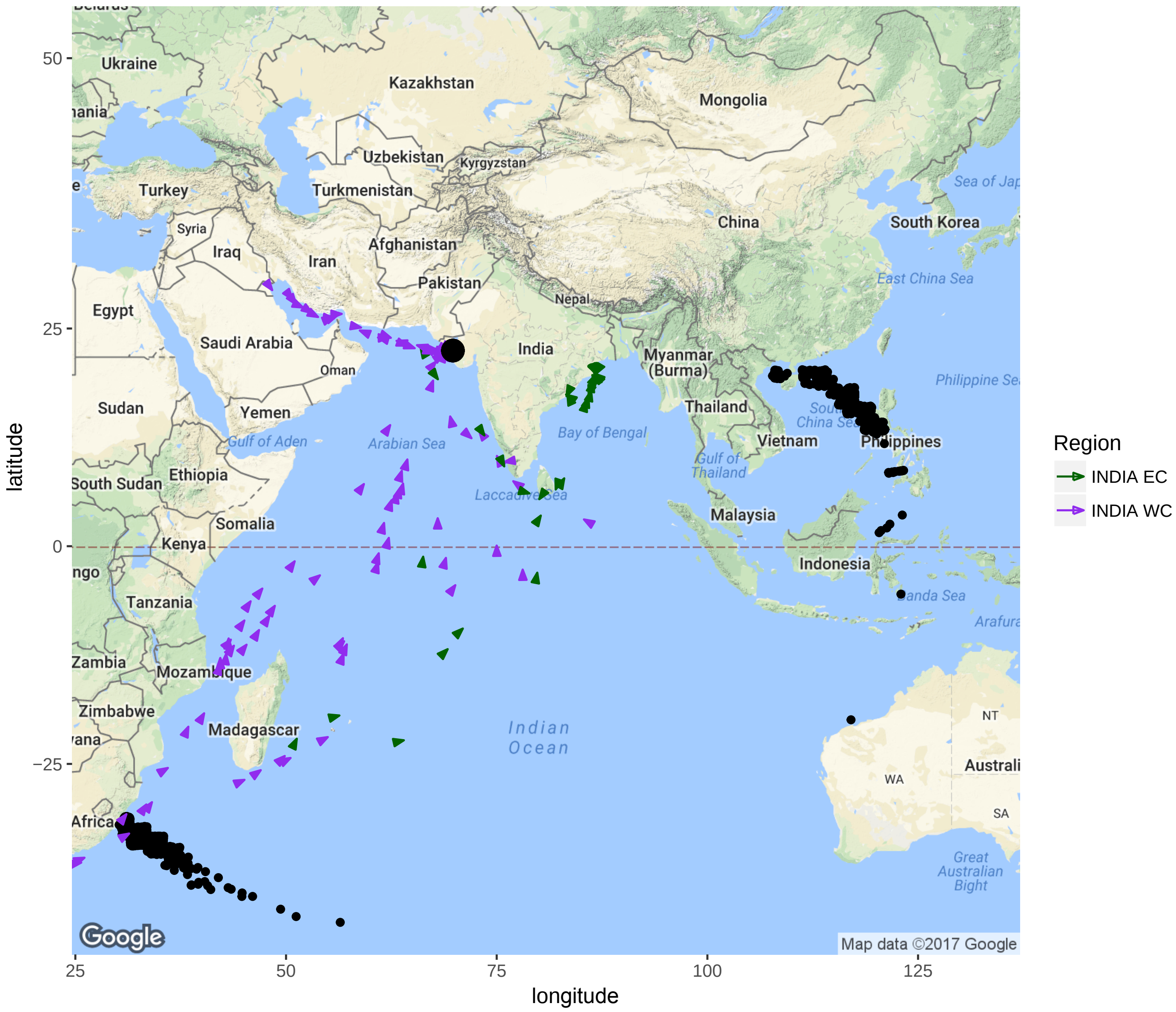


Figure 10: **Far East proximity boundary for laden vessels**
This figure shows vessel positions with a distance to Chiba (the big black dot) between 1900 n.m. and 2000 n.m. which is illustrated by the small black dots. The small black dots gives an indication of the boundary of availability condition 3. The triangles are positions of vessels which enter a fixture loading in the Arabian Gulf.

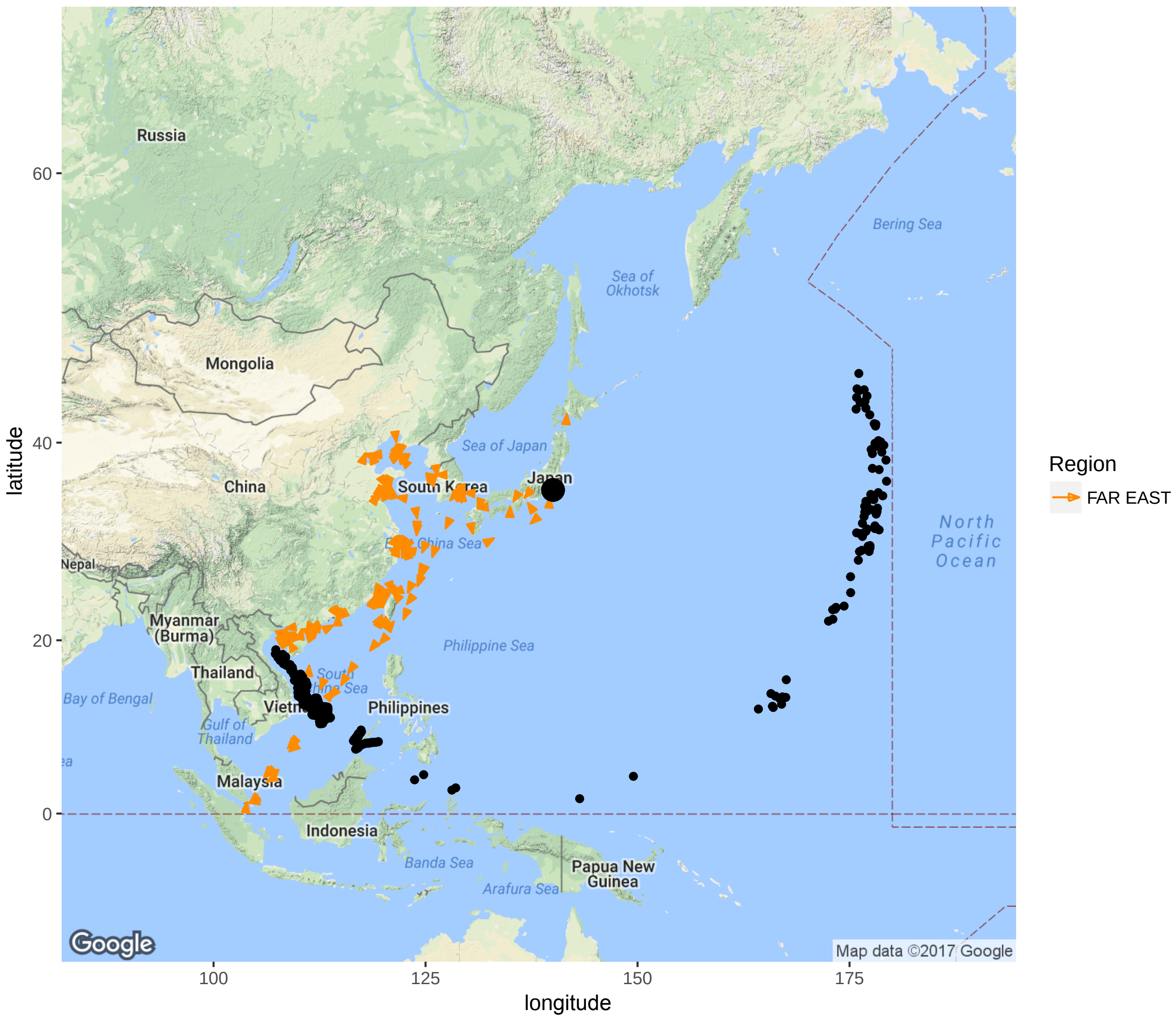
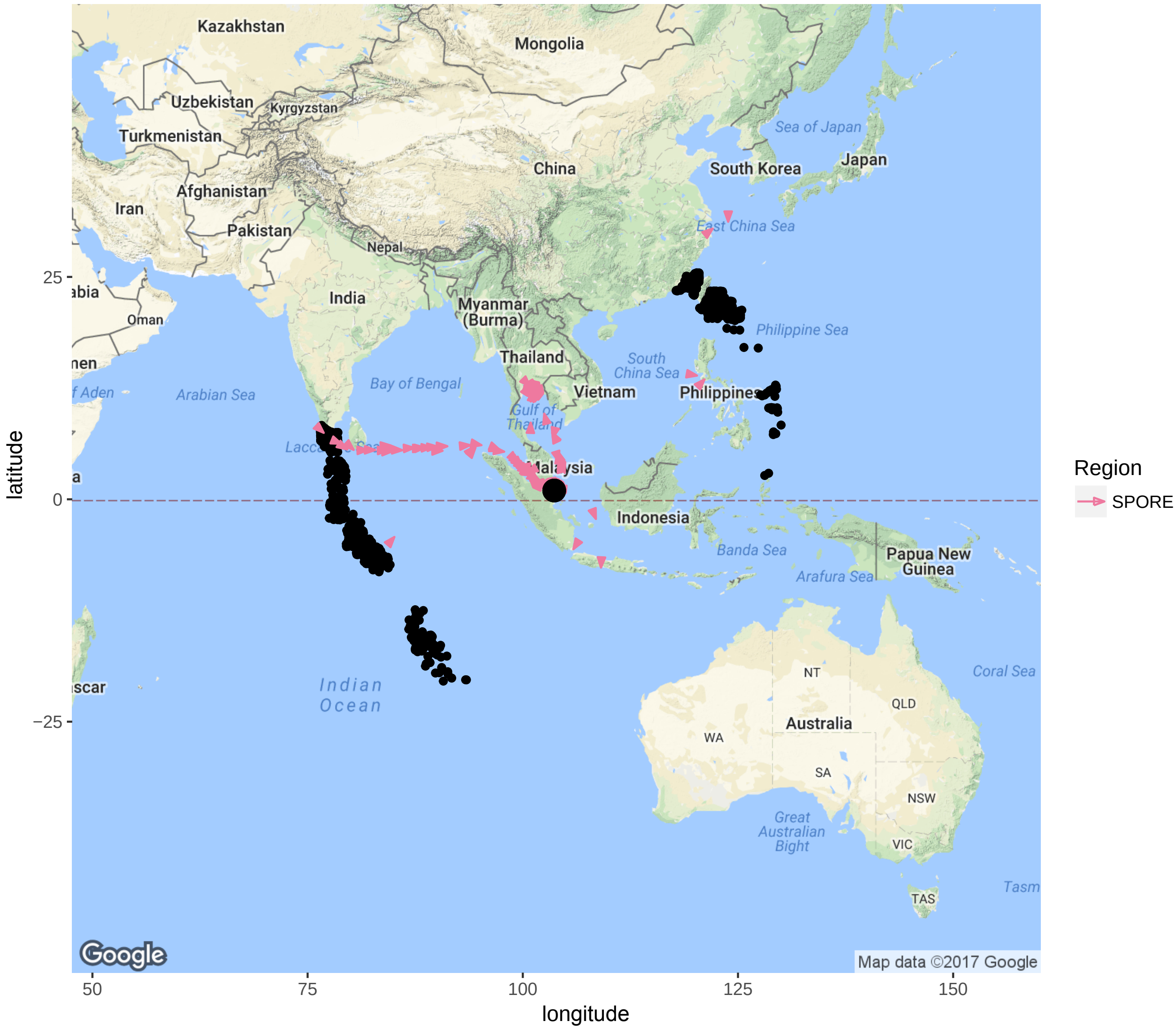


Figure 11: **Singapore proximity boundary for laden vessels**
This figure shows vessel positions with a distance to Singapore (the big black dot) between 1600 n.m. and 1740 n.m. which is illustrated by the small black dots. The small black dots gives an indication of the boundary of condition 4. The triangles are positions of vessels which enter a fixture loading in the Arabian Gulf.



C Lag selection, rank tests and over-identification test

Table 10: **Lag selection**
This table shows the SBIC criteria (Schwarz 1978). The VECM is estimated with one lag as it minimizes the SBIC.

Lags	1	2	3	4	5
SBIC	-14.048	-13.895	-13.778	-13.616	-13.362

Table 11: **Cointegration eigenvalue test**
This table shows the Johansen (1991) cointegration eigenvalue test for $y_t = [\ln TD3_t \ \ln FFA_t \ \ln Ratio_t]$. The $Ratio_t$ coefficient is restricted to zero in the cointegration term as the unit root test in Table 4 indicates that it is stationary. $ECT_t = \ln TD3_t - 1.24 \ln FFA_t + 0.58$

Eigenvalue test	Test Statistic	10pct	5pct	1pct
H_0 : r $\leq$ 1	3.62	7.52	9.24	12.97
H_0 : r = 0	17.69	13.75	15.67	20.20

Table 12: **Cointegration trace test**
This table shows the Johansen (1991) cointegration trace test for $y_t = [\ln TD3_t \ \ln FFA_t \ \ln Ratio_t]$. The $Ratio_t$ coefficient is restricted to zero in the cointegration term as the unit root test in Table 4 indicates it is stationary. $ECT_t = \ln TD3_t - 1.24 \ln FFA_t + 0.58$

Trace test	Test Statistic	10pct	5pct	1pct
H_0 : r $\leq$ 1	3.62	7.52	9.24	12.97
H_0 : r = 0	21.31	17.85	19.96	24.60

Table 13: **Over-identification restriction test**
This table shows the linear restriction test. It tests whether the cointegration vector can be reduced to the spot-FFA basis.

$ECT_t = \ln TD3_t + \beta_1 \ln FFA_t + \beta_2$	Test statistic	p-value
$H_0 : \beta_1 = -1, \ \beta_2 = 0$	3.7386	0.4425